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Agricultural Systems 85 (2005) 271–288
AGRICULTURAL SYSTEMS
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A simulation model to study land use strategies in swidden agriculture systems

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Abstract

Development has ended isolation in many parts of Kalimantan, Indonesia, and provides previously isolated communities with the opportunity for greater involvement in a market economy. This paper describes the use of a simulation model to study the possible impacts of greater involvement in cash cropping in swidden agricultural systems. The model uses both individual-based and rule-based modelling approaches. The model formulation is based on a previous report of the social structure, culture and agricultural production system of the Kantu' in West Kalimantan [Dove, M.R., 1985. Swidden Agriculture in Indonesia: The Subsistence Strategies of the Kalimantan Kantu'. Mouton Publishers, Berlin]. The model simulates: (1) births, deaths, marriage, household formation and dissolution; (2) land use decisions on the type, number and location of swidden cultivation; and (3) tracks the consequences of those decisions at a landscape level as well as the economic welfare of the households. The model deals with swidden cultivation of rice and the planting and tapping of rubber. The paper presents a simulation 'experiment' that compares different land use strategies under a scenario of fluctuating rubber price. An important finding is that maintaining swidden cultivation as 'an option' in the farming system, rather than permanently replacing swidden cultivation with cash cropping, appears to be a safer strategy to moderate the impact of commodity price fluctuations.

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0308-521X/$ - see front matter
doi:10.1016/j.agsy.2005.06.011

Keywords: Individual-based model; Household dynamics; Land use decision; Landscape dynamics

1. Introduction

Swidden cultivation is a prominent land use practice in many parts of Indonesia. Sunderlin et al. (2000) estimated that there are approximately six million people practising swidden cultivation throughout Indonesia's five main outer islands including Kalimantan (the Indonesian part of Borneo island). In Kalimantan, swidden cultivation has long been practised by traditional communities living in isolated regions, where rivers form the main transportation routes. These communities have a subsistence economy in which swidden cultivation of rice is the main economic activity. Nevertheless, community members also engage in non-subsistence activities such as working for wages and growing cash crops such as rubber and rattan (Weinstock, 1983; Dove, 1985). In recent years, however development has ended isolation in many parts of Kalimantan (e.g. Wadley, 1997). Previously isolated villages are now connected by roads creating larger markets. Hence, the ending of isolation provides many previously isolated communities with an opportunity for a greater involvement in the market economy.

The question is then: what would be the best land use strategy for swidden farmers to respond to this opportunity? Would abandoning swidden cultivation and shifting to cash cropping be more profitable for farmers? This paper presents a simulation model that can be used to study the possible impacts of greater involvement in cash cropping on a swidden agricultural system.

2. Modelling swidden agriculture system

There have been a number of models developed for swidden agriculture systems, which vary in terms of the purpose of the model, modelling approach, as well as aspects to be considered. For example, Dvorak (1992) developed an analytical model based on microeconomic theories to study the relationship between the labour economy of shifting cultivation and the cropping and fallow cycle in the shifting cultivation system widely practiced by West African farmers. This study suggested that variation in cropping intensities can be explained by environmental and economic factors regulating how clearing and weeding contribute to output. Wilkie and Finn (1988) developed a simulation model to investigate the long-term effects of swidden cultivation on forest composition and landscape structure in the Ituri forest of north-eastern Zaire. This model differs from Dvorak's model in its explicit treatment of spatial and ecological aspects (e.g. distance, field position and succession) as well as inclusion of the land tenure system and population growth. Wilkie and Finn's study showed that the distribution of forest cover types and the associated spatial pattern of the landscape (number and size of patches) varied predominantly with different population pressures, land tenure systems and rules for minimum fallow length. Gilruth et al. (1995) developed a dynamic spatial model of shifting cultivation in the highlands of Guinea, West Africa. This model differs from Wilkie and Finn's model mainly in its more realistic representation of the landscape (based on remotely sensed data) and treatment of spatial aspects (i.e. topography and proximity to village) for selection of new fields. A few models that incorporate swidden agriculture in the Indonesian setting have also been developed (e.g., Iskandar, 1994, Angelsen, 1999). Angelsen (1999) developed analytical models based on microeconomic theories to examine the effects of various factors determining expansion of agriculture in frontier areas (deforestation) under different economic assumptions.

The model presented in this paper was developed by Sulistyawati (2001). The model formulation reflected the social structure, culture and agricultural production system of the Kantu', a swidden cultivation community in West Kalimantan (Dove, 1985), and was constructed based on the data provided by Dove (1985), supplemented by data from similar ethnic groups in Kalimantan/Borneo.

The approach is essentially a combination of individual-based modelling widely used in ecology (Urban and Shugart, 1992) and 'microsimulation' modelling that has been used in the field of demography, anthropology, sociology and economics (van Imhoff and Post, 1998). The model integrates the demographic, socio-cultural, economic and ecological factors affecting land use decisions in swidden agricultural landscapes. It differs from the aforementioned models mainly in the explicit representation of each household, which is assumed to be the main unit of land use decision-making. Households are represented as discrete entities, each having unique attributes such as members and property ownership. Because the households and the landscape are explicitly represented, the model can be used to explore implications of assumed land use strategies for both the landscape and household condition.

This paper presents the application of the model for exploring possible impacts of greater involvement in cash cropping in swidden agricultural systems. Assessment of the impacts are conducted through a simulation 'experiment' that compares two land use strategies, which differ in the degree of involvement in cash cropping, under a scenario of fluctuating commodity prices and two scenarios of population growth (i.e., growing and constant). Before describing the model, a brief introduction to the Kantu' community is presented.

3. The Kantu'

The Kantu' community lived in West Kalimantan Province near the border with the Malaysian state of Sarawak. In 1974–1976, Michael R. Dove conducted a study in an isolated longhouse that was established in 1957 by nine households on a territory of approximately 10 km^2. The Kantu' lived in a largely subsistence economy where swidden cultivation of rice was the main activity. They also engaged in many forms of cash-earning activities to earn money for buying basic goods. Nevertheless, tapping rubber was the primary source of cash. Usually, rubber seedlings were mixed with crops in swidden and left to grow along with other secondary species when the swidden is abandoned. A household was the primary unit of production, consumption and land appropriation. Swiddens were cultivated largely using household's labour, and rice was mainly for household consumption.

Marriage had important consequences with regards to rights to household property. The departure of an out-marrying child meant that he/she would lose rights to property of the natal household but would acquire rights in the household into which he/she married. This means that an out-marrying child would not get inherited land from the parent. After a brief post-marital residence with parents, married couples would leave the parents' household to establish their own household (i.e., 'household partition'), except the youngest sibling, who would stay permanently with the parent.

Households acquired ownership to land by felling primary forest to make a swidden. The feller had the primary right to re-use the regrowth (fallow) plot. Upon a household partition, rubber groves and other property were divided between the parents' and the newly formed child's household, but this did not apply for fallow plots. The rights to re-use the secondary plots were shared between the parents (first generation) and one or more children households (second generation) created through partitions. However, these rights could not be shared with additional households created by further partition of the children's households (i.e. third generation, from the perspective of the feller household). In other words, the rights could only be shared between 'two successive generations'. Dove (1985) asserted that once the third-generation households were formed, it was possible to divide the forest rights between the two older generations. Following land inheritance, individual households of the second generation formally acquired the forest rights and these households could then share these rights with the households of their children without violating 'two successive generation' rule.

4. Model overview

This paper only describes the main features of the model; a more detailed account of the model can be found in Sulistyawati (2001). The model simulates the development of a hypothetical swidden community along with the landscape where the swidden cultivation is carried out. The model uses a rule-based approach as opposed to mathematical or statistical approaches. The dynamics of the system is simulated from a set of rules that are represented as a series of IF-THEN-ELSE statements. These rules represent a set of hypotheses about the social and ecological systems and could also be viewed as a simplification of an otherwise very complex real life situation. The simulation model was implemented in a PC environment using the Borland DELPHI software package.

The model (Fig. 1) is organized into four modules: population dynamics, land use decision-making, vegetation dynamics and production evaluation modules. The population dynamics module simulates the development of a community by 'creating' persons (i.e. birth) as well as 'creating' new households through household 'partition'. The land use decision-making module simulates the decision on 'what' agricultural activities to perform and 'where' they are performed. The model deals

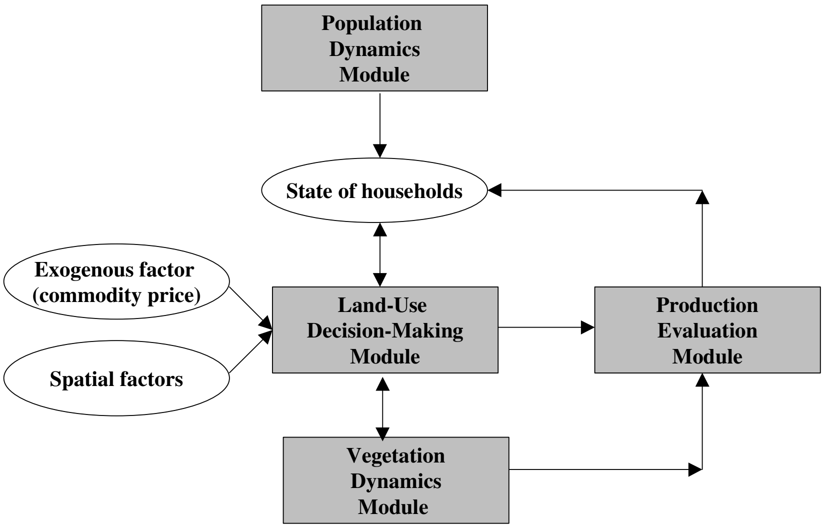

Fig. 1. The model framework.

with three agricultural activities – making swiddens (dry-land fields) for growing rice only, making swiddens for growing rice intercropped with rubber, and tapping rubber. The execution of various cultivation tasks (e.g., slashing, felling and harvesting) is also simulated in this module. The production evaluation module determines whether the household's demands for rice and cash in the current year are met. Rubber tapping is also simulated in this module. The vegetation dynamics module simulates the successional changes following the abandonment of swiddens, maturation of rubber plots and rice yield. The model runs at an annual time step for most processes, with the exception of cultivation tasks, which use a daily time step.

5. Key assumptions of the model

5.1. Population dynamics module

The simulated community is a closed community where the population size is entirely determined by births and deaths. Each person of a given age, sex and/or marital status has a chance of death, giving birth and getting married in each year. The demographics are formulated using a Monte Carlo approach whereby specific probabilities (for death, giving birth and getting married) are associated with the state of each person (e.g., age, sex and marital status). Each person belongs to a household through birth, marriage (post-marital residence) and adoption. Every person in a household has a 'membership' status (i.e., head, heir or member), and this status determines who will be the household's successor. Marriage occurs among single or widowed persons of marriageable ages except among those prohibited by incest taboo. In the model, the main criterion of spouse selection is age difference. Marriage does not initiate formation of a new household for newlywed couples. Instead, newlywed couples stay temporarily with the parent of either the wife or husband until the time of 'household partition'. Household partition is triggered by the presence of two married sibling at the same household. Partition may happen several times in a household depending on the number of children. In each partition, the departing party (or 'junior' household) acquires a share of the 'parent' or 'senior' household's wealth; that is, rice, cash and rubber plots. However, (fallow) lands are not inherited at this stage. Nevertheless, the 'junior' household can still get access to the 'senior' household's lands in a land sharing arrangement. The formal land inheritance takes place later and is triggered by household partition occurring in one of the 'junior' households.

5.2. Land use decision-making module

The model represents a community living in a subsistence economy where the level of agricultural production is geared toward fulfilling the household's customary requirement (Sahlins, 1972), rather than profit maximization. It is assumed that the household size determines the overall household demand for products (i.e., rice or cash). Thus, the magnitude of demand changes dynamically throughout the simulation. The total demand for rice is the sum of rice required for eating, for seed and for paying rice debts; whereas it is assumed that the total demand for cash is only for buying basic staple goods (e.g., salt, sugar and kerosene). We are aware that those particular assumptions may be too simplistic; however, they were taken to simplify the model. Furthermore, the main source of labour are the household members of working ages, but household labour can be supplemented by hiring labourers from other households.

The model design includes a 'default' land use strategy that reflects the subsistence nature of the Kantu'. In the default mode, households have a strong preference for growing their own food and cultivating swidden always take precedence over tapping rubber. This means that tapping rubber is only done when there is no work to be done in the swiddens. The model deals with two types of swidden – swiddens for growing rice only and swiddens where rice is intercropped with rubber. Rice is cultivated for one year. Upon the abandonment of rice cultivation, the latter type of swidden will develop into a rubber agro-forest. In this model, creating swiddens for rice and rubber is the only means to plant rubber. The model assumes that households intend to ensure the continuity of rubber production by having at least one mature (tappable) and one immature rubber plot. Therefore, the timing of rubber planting is set soon after the last immature rubber plot has come into production.

Given the level of rice demand and the size of available labour, each household decides the 'number', 'type' and 'location' of swiddens to be made. The type of swidden can be swidden-for-rice-only or swidden-for-rice–rubber. Both types of swiddens can be cultivated in the same year if the rubber planting is 'due' on that year. A summary of the core rules for simulating land use decision-making is presented in Fig. 2.

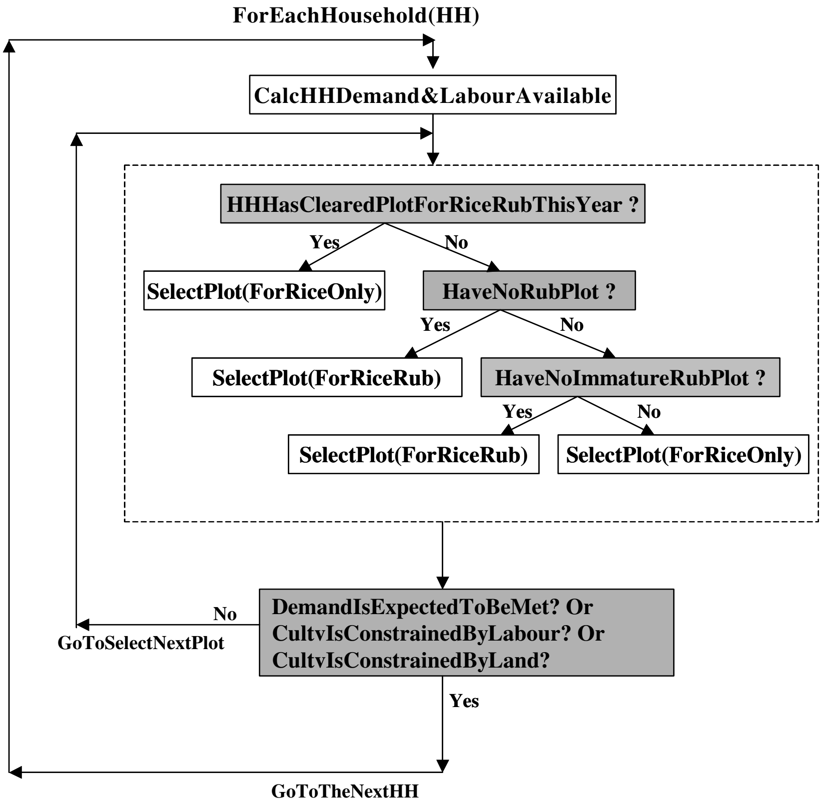

Fig. 2. Summary of the core rules for simulating land use decision-making.

Selection of swidden is a spatial process and is based on the following criteria: distance to longhouse, distance to the river, distance to last-year swidden, distance to same-year swidden, distance to other households' swidden, vegetation type, ownership and topography. The above-noted, distance-related criteria were selected to reflect the Kantu' strategy in terms of minimizing travel time, the facilitation of labour exchanges between households that are cultivating adjacent swiddens and diversifying the microenvironment among household's swiddens made in the same year. In a given year, new swiddens can be made in either primary forest or secondary forest (fallow). These confer different benefits to the household. A swidden made in primary forest requires more labour, but rewards the household with permanent ownership to the land. Alternatively, a swidden made in secondary forest requires less labour and also gives a higher yield. Swiddens are only made in primary forest if the household has at least one adult male. Therefore, clearing primary forest is a means to establish ownership to land and consequently all fallow lands are owned. The model takes into account the possibility of land borrowing but imposes restrictions regarding who can lend and borrow land.

Table 1
Calculation of the Site Index

Site Index $= F_1W_1 + F_2W_2 + F_3W_3 + \cdots + F_8W_8$

Factor	Description	Weight
F_1	Distance to longhouse (1–5)	0.0533
F_2	Distance to the river (1–5)	0.0533
F_3	Distance to last-year swidden (1–5)	0.1487
F_4	Distance to same-year swidden (1–5)	0.0533
F_5	Distance to other households' swiddens (1–5)	0.1487
F_6	Vegetation type preference (1–5)	0.3404
F_7	Ownership preference (1–5)	0.1487
F_8	Topographical preference (1–5)	0.0533

The swidden selection is simulated by evaluating the relative 'attractiveness' of each potential site (i.e., grid square) according to the aforementioned selection criteria. The numerical expression of the site attractiveness is in the form of a 'site index' (Table 1). We developed a set of rules to assess the magnitude of household preference for each selection criterion (or 'factor') expressed on 1-to-5 scale with the order of scale corresponds to increasing preference. The method to derive the 'weights' (W) is based on Eastman (1997), and it involves pair-wise comparisons on the relative importance of two selection criteria. The assessment of the relative importance of all pairs of selection criteria is based on educated guess (see Sulistyawati, 2001). Once the site index is calculated for all potential sites, the one with the highest site index is selected by the household in question for making a swidden plot.

Following swidden selection, the execution of cultivation tasks (i.e., slashing, felling, burning, planting, weeding and harvesting) is simulated on a daily basis based on the Kantu's cultivation schedule. Some tasks are time-constrained (e.g., planting). If a given household does not have sufficient labour to finish a cultivation task within the specified duration, the household hires labour from other households with labour surplus. Since the execution of cultivation tasks is simulated on a daily basis, the number of 'idle' days (i.e., no swidden work) can be tracked. It is only during these idle days that the household labour is made available for tapping rubber.

5.3. Production evaluation module

The production evaluation module firstly evaluates whether the 'rice available' to a household can meet the household's demand. The 'rice available' consists of rice stored from previous year surpluses (if any), rice harvested in the current year and rice earned from working in other household's swiddens (wages). The household's cash demand is the amount of cash required to purchase staple items (i.e., sugar, cooking oil, kerosene, textile and salt) and for paying any cash debts. However, if the 'rice demand' in the current year cannot be met, the cash demand is increased to account for the additional cash to buy rice. The household's cash demand and available labour determine the intensity of rubber tapping. Households having no or limited access to tappable rubber plots can tap other households' rubber in a share tapping arrangement. The prices of goods in the 'default' model are assumed to be constant and currently set to reflect the prices in the region of the study site in 1978. If the cash production from rubber tapping still cannot meet the household's cash demand, the household attempts to secure a rice or cash loan from other households whose rice or cash are in surplus.

5.4. Vegetation dynamics module

The model simulates vegetation succession as a discrete transition from one state into another (see Fig. 3). The model specifies the timing of transition based on the time elapsed since last abandonment, which is currently at 1, 2, 6, 21 and 100 years for 'old' swidden, shrub, young secondary forest, old secondary forest and primary forest, respectively. Similarly, swiddens intercropped with rubber undergo the following sequential changes of state: immature, mature and 'old' rubber with the timing of transition currently set to 1, 11 and 41 years, respectively. Rice yield is set to be a function of the fallow duration with the yield decreasing as the fallow duration shortens. This is a simplifying assumption because empirical studies show the difficulty in assigning fallow length as a single determining factor affecting yield (Mertz, 2002). Further, the yield from primary forest is assigned to be less than that from a long fallow plot because of the problem of incomplete burning.

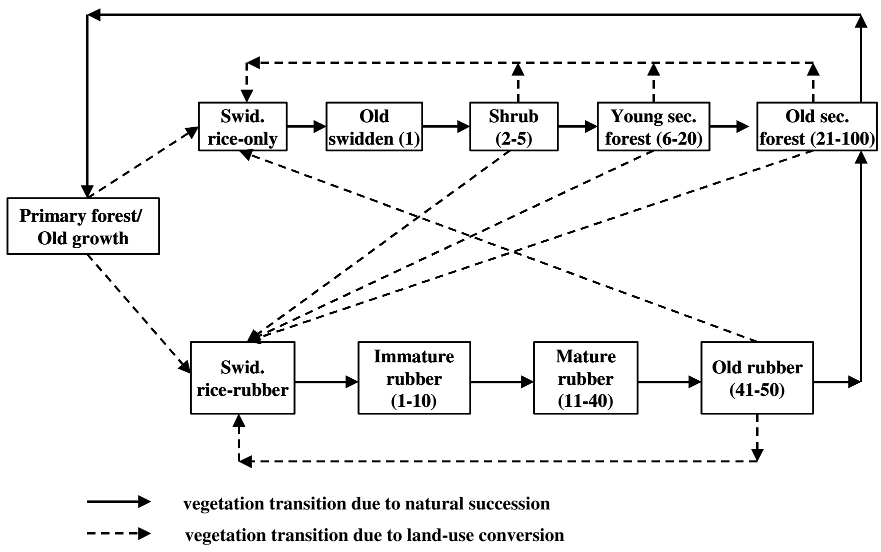

Fig. 3. The sequences of vegetation changes simulated by the model. The age of vegetation, i.e. years since last abandonment is given in brackets.

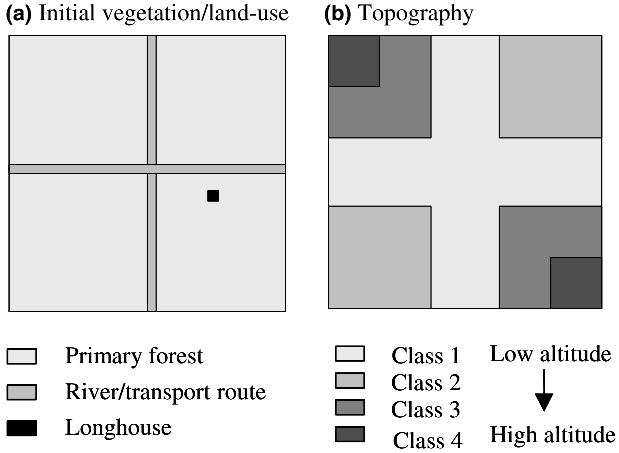

Fig. 4. Initial landscape configuration used in the model runs.

6. Initial conditions

The initial community consists of nine households with predefined age and sex structure having the same initial property holding. The current version of the model uses a simple landscape representation (see Fig. 4) comprising two intersecting rivers, a longhouse (or settlement) and lands initially covered by primary forest. The topography is arbitrarily constructed to represent a longhouse located in a valley. The landscape represents the community's territory with an area of 12.5 km^2 (a 50×50 matrix of 0.5 ha cells).

7. Model validation

Model validation is usually taken to mean the process of demonstrating whether the model simulates observed behaviour to some pre-specified level of accuracy consistent with the intended application and within its application domain (Brown and Kulasiri, 1996). Operationally, it is commonly carried out by comparing the model outputs with data that are independent of those used to construct the model. However, validation testing in this way can be difficult because of the lack of independent data, especially in ecological systems. Often, the model can only be validated using limited data and a good test of the model is usually the plausibility of the model output.

The model presented here is a complex model that yields very rich behavior. The validation of this model, (see Sulistyawati (2001) for a more detailed description) was conducted by comparing the model outputs with available data. The focus of the comparison was not so much on the exact magnitude of data agreement but more on the range and plausibility of the trend in model output. The main tests are summarized in Table 2

Table 2
Comparisons between model output and observations

Variables	Model output	Observations	Data source
Population growth	2.6%[a]	2.1–3.9%	Population of Nanga Kantuk village 1984–1999 (field note, 1999)
Distribution of household size	Similar[b]	Similar	Selected Borneo Communities[c]
Disappearance of primary forest	Around year 45	Gone by 1999 or 42 years since initial settlement	The Kantu' (field notes, 1999)
Land holding of the initial households at year 20	31 ha	26 ha	The Kantu' (Dove, 1985)
Land inequality	Present	Observed[d]	The Kantu' (field note, 1999)

[a] Average rate for 75 years.
[b] Statistically identical according to the Kolmogorov-Smirnov test at $\alpha = 0.01$ (Sokal and Rohlf, 1981).
[c] Summarised data (Dove, 1981; Drake, 1982; Freeman, 1992; Wadley, 1997 Dove, pers. comm.).
[d] But the exact magnitude is unknown.

For the population variables, the simulated population growth (~2.6% annually) was within the range estimated in the study area (2.1–3.9%). The simulated pattern of the distribution of household size was a classical bell curve with small and large households occurring in smaller proportions than medium-sized households. This was similar to the observed pattern in comparable Bornean communities. For the land-use variables, the model predicted the disappearance of primary forest around 45 years after initial settlement which was in close agreement with the observations (~42 years). The observed rate of land holding accumulation among the pioneering Kantu' households (averaging 26 ha per household after 20 years) was slightly lower than the simulated accumulation (averaging 31 ha per households after 20 years). In terms of social aspects, a degree of inequality in land holding has been observed in the study area and the model also simulated the emergence of inequality in land holdings as the community develops. These comparisons suggest that, in general, the model outputs are realistic and plausible with respect to gross population and landscape characteristics.

8. The simulation experiment

In this paper, the model is used for exploring the implications of different land use strategies adopted by swidden farmers under fluctuating commodity prices and increasing population. The 'design' of the simulation experiment is as follows. We created two versions of the model that differ in terms of the land use strategy. Each version was then run under two scenarios of population growth – constant and growing. Applying different scenarios of population growth to both land use strategy versions was our attempt to try separating population growth effects from land use strategy effects. An identical scenario of commodity price fluctuations was used for all simulation modes.

In the 'default' version, as described earlier, households are assumed to have a strong preference to grow their own food. Thus, households attempt to clear swiddens each year irrespective of the quality of the available sites. Accordingly, cultivating swidden always take precedence over tapping rubber. This 'default' land use strategy is contrasted with a 'modified' land use strategy where a simple measure of economic efficiency is used to influence the land use decision.

In the 'modified' version, it is assumed that households attempt to pursue the most efficient way to obtain rice, either by: (1) growing rice in swiddens or (2) tapping rubber and then using the cash to buy rice. The 'modified' version uses the labour needed as a measure of 'economic efficiency'. It is assumed that households select the method of obtaining rice that minimizes the labour requirement. In principle, a household may purchase its entire annual rice requirement using cash earned from rubber tapping. This may occur if the labour requirement for rubber tapping is less than the labour requirement for swiddens. The commodity price of rubber, the available household labour, the quality of lands owned and the total area of tappable rubber plots, all determine which strategy is more efficient. Therefore, over the years, households may switch from one method to another depending on the above circumstances. Hereafter, we call this modelled strategy, the 'flexible' mode, as opposed to the 'default' mode, which acts as a 'control'. Meanwhile, the scenarios of population growth were made by varying the input parameters, particularly on fertility rates. For the population growth scenario, we used a fertility schedule that produces a population growth rate which resembles that of the study area. Then, we modified the fertility schedule to *approximate* a constant population.

The commodity price is treated as an exogenous variable. To simplify the scenario of price changes, the rice price is held constant but the rubber price varies according to a prescribed function that specifies the ratio between the rubber and rice prices (Fig. 5(b)). The fluctuating rubber price is introduced after year 15, after which most households have productive (tappable) rubber plots. Each simulation mode was then run for 75 years duration. The simulation duration represents the development of a community starting from territorial occupation by 'pioneer' households, followed by household proliferations until the formation of second and/or third generations. This duration also allows the simulation of vegetation succession and intergenerational land distribution through inheritance. Since parts of the model are stochastic (see above descriptions), multiple runs (20 replicates) are used to summarize the resulting dynamics. The results are presented as the average of the 20 replicates.

9. The simulation results

Many aspects of the community life and landscape features simulated by the model can be extracted for examination. However, only those of immediate interest are presented here. The simulated population increases from about 5 to about 36 persons per km^2 under the growing population scenario (Fig. 5(a)). This increase follows an approximate exponential growth pattern with the annual growth rate of $\sim$2.6%.

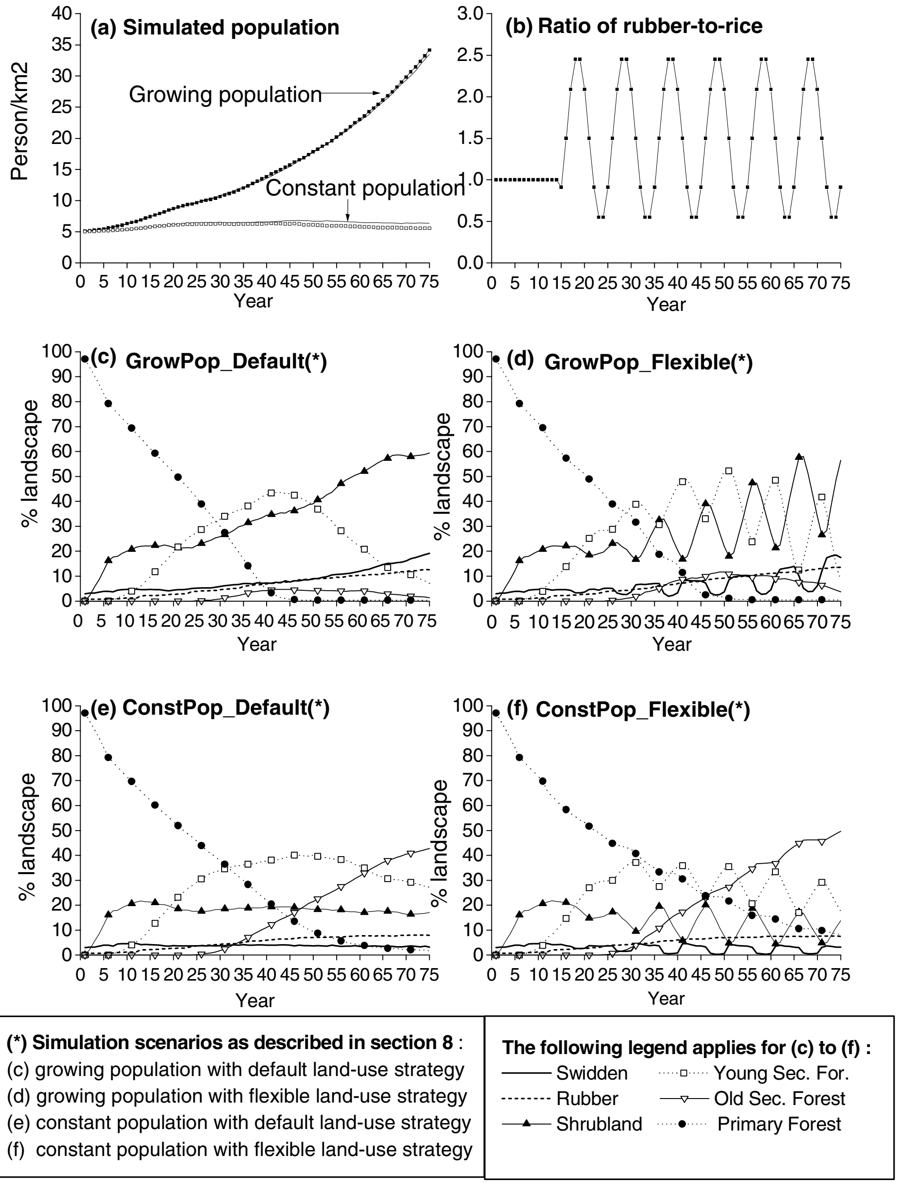

Fig. 5. Simulated population changes, prescribed changes in rubber prices and vegetation composition of the landscape.

Meanwhile, the simulated population under the constant population scenario stabilizes at 5 persons per km^2 (Fig. 5(b)).

Under the growing population scenario (Fig. 5(c) and (d)), landscapes in the default and flexible modes are eventually dominated by shrublands, but the dynamics differ. The extent of swidden cultivation in the default mode increases steadily which reflects the steadily increasing population. Alternatively, in the flexible mode, the extent of swidden cultivation fluctuates inversely with the rubber price. However, swidden cultivation never ceases completely. This means that while many households do shift to tapping rubber when rubber prices are high, some do not, mostly because they do not own a productive rubber plot.

Meanwhile, the fluctuating trend of swidden in the flexible mode triggers complementary trends in the area covered by shrubland and young secondary forest. During the periods of frequent swidden cultivation, shrublands tend to increase because the abandoned swiddens enter this vegetation state. In contrast, young secondary forests tend to decrease because this vegetation type is preferred for making swiddens. An interesting feature is the continued presence of old secondary forests, albeit in a small proportion, until near the end in both simulation modes. This happens because, while the average land holding per household decreases, there are one or more households with large land holdings so that they can afford to leave a few plots in fallow for a very long period (>21 years).

The landscape dynamics under the constant population scenario differ significantly to those under the growing population scenario (Fig. 5(e) and (f)). In both the default and flexible mode, the landscape is eventually dominated by old secondary forests. Meanwhile, the rate of primary forest clearing is slower in the flexible mode than in the default mode. Actually, a similar trend also prevails when comparing the outputs of the default and flexible mode under the growing population scenario. However, the effect of a flexible land use strategy in slowing the rate of primary forest clearing is more significant in the constant population than in the growing population scenario.

Another interesting difference is on the extent of swidden in the flexible modes under different population growth scenarios. Under the growing population scenario, although the extent of swidden cultivation during the periods of high rubber price is low it never ceases completely (Fig. 5(d)). Meanwhile, under the constant population scenario, the extent of swidden cultivation during the same periods approaches zero, which means that almost all households forego swidden cultivation and shift to tapping rubber (Fig. 5(f)). This indicates that, under the constant population scenario, all households own productive rubber plots so that they can readily shift to tapping rubber when the rubber price is high.

As a measure of the economic welfare of households, we used the proportion of households whose available rice can meet the annual demand. In interpreting the trends on the rice sufficiency (Fig. 6(a)), it should be noted that the amount of rice accounted for in this measure refers to the rice produced in swiddens, and excludes rice bought from the proceeds of rubber. Thus, occasional drops in the number of households that are sufficient in rice are found in the flexible modes, which are a consequence of foregoing swidden cultivations during years with a low rubber price.

The simulation results suggest that not all households attain high rice sufficiency in the default modes, even under the constant population scenario. A lack of access to productive land and/or household labour constraints are the main reasons for the

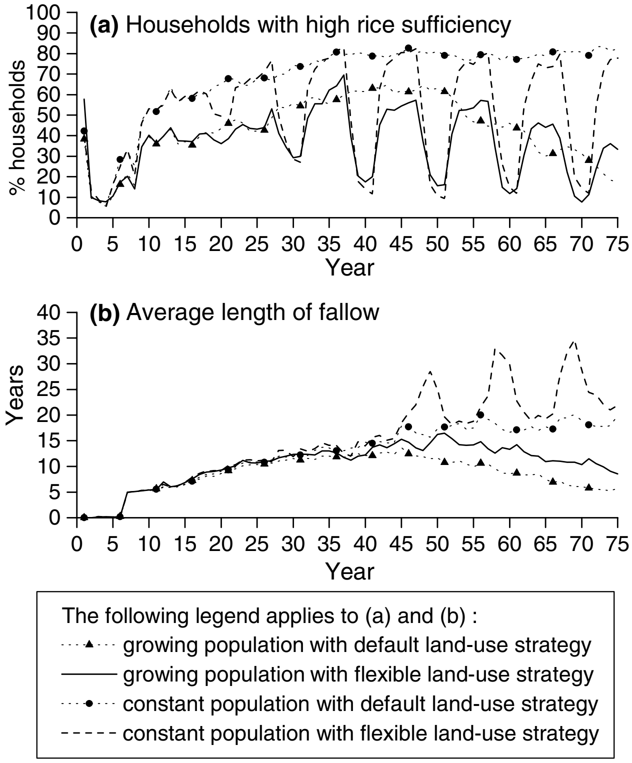

Fig. 6. Simulated changes in rice sufficiency and fallow length. Note that high rice sufficiency is defined as a household whose rice currently available can meet the annual demand.

trends under the growing population scenario (see Sulistyawati, 2001). After about 50 years, the decrease in proportion of households who are sufficient in rice (Fig. 6(a)) is matched by the decrease in the fallow duration (Fig. 6(b)). This arises, because in the model, rice yield is solely a function of fallow length. The shortening length of fallow ultimately arises because of the increasing population size on a finite territory. Meanwhile, labour constraints are most likely the reason for the failure of some households to attain high rice sufficiency under the constant population scenario.

In general, the effect of land use strategy on rice sufficiency is not significant under the constant population scenario. However, it is significant under the increasing population scenario. In this case, there are more households achieving high rice sufficiency during the years with low rubber prices in the flexible mode than in the default mode during the last-25 years when the pressure for land is highest. Temporary shifts into tapping rubber during the good-price years leave land in fallow for a longer period. As the land productivity increases under a longer fallow period, this action would give households a better quality of land at the time when they have to cultivate swiddens during years with low prices.

10. Discussion and conclusion

The default mode represents an extreme form of subsistence agriculture that was observed during Dove's study. Here, price fluctuations only affect the intensity of rubber tapping but not the extent of swidden cultivation. Since cash is assumed to be sought to meet a specific end, the rubber production is low when the rubber price is high since farmers need to tap less rubber and vice versa. In contrast, fluctuations in the rubber price in the flexible mode affect the level of swidden cultivation. When the rubber price is high, most swidden cultivation is abandoned, whereas swidden cultivation is resumed when the rubber price is low. Hence, the flexible land use strategy represents a swidden community with more involvement in cash cropping.

The main lesson learnt from this simulation modelling study is that a land use strategy that allows a shift of the resources (land and labour) between swidden cultivation and cash cropping – dependent on the prevailing commodity prices – is a sound land use strategy for swidden communities living under increasing population pressure. This study has shown that maintaining swidden cultivation as 'an option' in the farming system, rather than totally replacing swidden cultivation with cash cropping, is a safer land use strategy because it allows farmers to revert back to swidden cultivation, to ensure some level of subsistence, when the commodity price drops (Cramb, 1993). In this way, the impact of commodity price fluctuation is moderated. Likewise, shifting to cash cropping when the commodity price is high would allow longer fallow periods. Thus, when the commodity price drops the households have access to more fertile lands. This study also shows that the extent to which this flexible land use strategy is beneficial would depend on the level of population pressure. Under low population pressure, the flexible land use strategy seems to have little effect on the level of rice sufficiency, but it could significantly slower the rate of primary forest loss.

One critical limitation of this model is that many aspects of the community life are assumed to be constant for 75 years. During such long period, it is likely that swidden communities respond to internal and external pressures in forms that are not captured by the existing model, such as adoption of new technology (e.g., rice intensification), out-migration and increased household demand beyond subsistence level (i.e., consumerism). Incorporation of scenarios of rice intensification and out-migration into the model could alter the dynamics of the system. Rice intensification is commonly associated with increasing capital, labour and yield. Although one may predict that increasing yield would reduce the extent of cultivated field, however, the need for more labour and capital due to intensification could actually increase the amount of rice demanded (for paying rice wage and getting more cash). Therefore, the actual impact on reduction of area cultivated would depend on the state of households, particularly with respect to availability of household labour. Out-migration would also affect the system through changing the availability of household labour. The current formulation of the model is based on subsistence agriculture. Incorporation of 'consumerism' would probably require a different goal such as profit maximization.

As a closing remark, we have demonstrated that individual-based modelling is an effective approach to integrating the demographic, socio-cultural and economic factors in a model of swidden agriculture. The significance of socio-cultural factors in swidden agriculture systems are well recognized but only rarely implemented in most of the existing swidden agriculture models.

Acknowledgements

This study is part of the Ph.D. project carried out by Endah Sulistyawati at The Australian National University and was funded by the Australian Government (AusAID). This paper was based on a presentation at the International Conference on Local Land Use Strategies in Globalizing World: Shaping Sustainable Social and Natural Environments, Copenhagen, August 21–23, 2003 with the support from QUE-Project of Department of Biology, Bandung Institute of Technology (ITB). We thank the anonymous reviewers for the suggestions to improve this paper.

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